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Indian Standard

TEST PROCEDURES FOR SEMICONDUCTOR CHARGED-PARTICLE DETECTORS

UDC 621·317·39·539·1·074·55:539·12:620·1

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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February 1987

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Indian Standard

TEST PROCEDURES FOR SEMICONDUCTOR CHARGED-PARTICLE DETECTORS

National Foreword

This Indian Standard which is identical with IEC Pub 333 (1983) 'Test procedures for semiconductor charged-particle detectors', issued by the International Electrotechnical Commission (IEC) was adopted by the Indian Standards Institution on the recommendation of the Nuclear Instrumentation Sectional Committee and approval of the Electronics and Telecommunication Division Council.

Wherever the words 'International Standard' appear, referring to this standard, they should be read as 'Indian Standard'.

Cross References

In this Indian Standard, the following International Standards are referred to. Read in their places the following:

International Standard	*Corresponding Indian Standard*
IEC Pub 50 (391) (1975) International electrotechnical vocabulary: Detection and measurement of ionizing radiation by electrical means	IS : 1885 (Part 63)-1985 Electrotechnical vocabulary: Part 63 Nuclear instrumentation
IEC Pub 340 (1979) Test procedures for amplifiers and preamplifiers for semiconductor detectors for ionizing radiation	IS : 11645-1985 Test procedures for amplifiers and preamplifiers for semiconductor detectors for ionizing radiation
IEC Pub 759 (1983) Standard test procedures for semiconductor X-ray energy spectrometers (*see* Note)	—

Note — The technical committee responsible for the preparation of this standard, has reviewed the provisions of this IEC Standard and has decided that it is acceptable for use in conjunction with this standard.

Only the English language text of the International Standard has been retained while adopting it in this Indian Standard.

Nuclear Instrumentation Sectional Committee, LTDC 26 [Ref : Doc : LTDC 26 (946)]

Adopted 24 September 1985

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INTRODUCTION

Symbols and glossary are to be found in Appendix A and general information regarding semiconductor charged particle detectors in Appendix B.

1. Scope

This standard applies to semiconductor radiation detectors which are used for the detection and high-resolution spectroscopy of charged particles. The measurement techniques described have been selected to be readily available to all manufacturers and users of semiconductor charged particle detectors. Some superior techniques are not included because the methods are too complex or require equipment (such as particle accelerators) which may not be readily available.

Test procedures for the associated amplifiers and preamplifiers are described in IEC Publication 340: Test Procedures for Amplifiers and Preamplifiers for Semiconductor Detectors for Ionizing Radiation.

2. Object

The object of this standard is to establish standard test procedures for semiconductor charged particle detectors. These detectors are in widespread use for the detection and high-resolution spectroscopy of charged particles. It is desirable to maintain standard test procedures so that measurements may have the same meaning to all manufacturers and users.

Not all tests described in this standard are mandatory, but tests which are used to specify performance shall be performed in accordance with the procedures described herein.

3. General requirements

The following requirements apply for all the tests and measurements described herein:

3.1 All measurements shall be performed with the device itself in total darkness, unless otherwise specified.

3.2 The ambient conditions shall be 20 °C and a pressure of less than 10^{-4} Pa (10^{-6} mm Hg), unless otherwise specified. (Precautions should be taken when working in the pressure region 10^{-2} to 10 Pa (10^{-4} to 10^{-1} mm Hg) because of corona discharge. Thus, some detectors that work satisfactorily at higher pressures may show degradation at pressures lower than $\approx 10^{-4}$ Pa (10^{-6} mm Hg).)

3.3 The values of the parameters measured shall be reproducible, within the specified precision after any and all of the tests have been performed.

3.4 The detector bias supply and other test equipment (amplifier, multichannel analyzer, etc.) shall not significantly influence the detector parameter measurements.

3.5 Maximum diode voltage, current, radiation flux ratings and other manufacturer-specified limits should not be exceeded or permanent changes of the device characteristics may result.

3.6 It shall be confirmed that radioactive sources used do not contribute to the resolution broadening. (This may occur especially with alpha particle sources due to self-attenuation and ageing effects.)

3.7 All data reported shall correspond to equilibrium conditions, unless otherwise clearly noted.

3.8 All measurements shall be made and reported in accordance with proper scientific practice. No changes in test system components (e.g. substituting a different preamplifier or detector) or changes in system parameters (e.g. changing gain or equivalent detector capacitance) may be made without complete system recalibration. Results which contain the effects of changing more than one parameter shall explicitly show the effects of each parameter on the measurement.

4. Resolution measurements

4.1 *Energy resolution*

The resolution of a detector system at a specific energy is determined by measuring the full width at half maximum (FWHM) of a spectral peak. A source of ionizing radiation emitting one or more prominent lines is used.

The detector is connected to an integrating (charge sensitive) preamplifier, main amplifier and multichannel analyzer as in Figure 1, page 11. The amplifier pulse shaping shall be quasi-Gaussian with a Δt of 3 μs. Alternatively, other shaping may be used, but the shaping characteristics shall then be clearly stated. The precision pulse generator should be switched off when measuring the resolution for ionizing radiation.

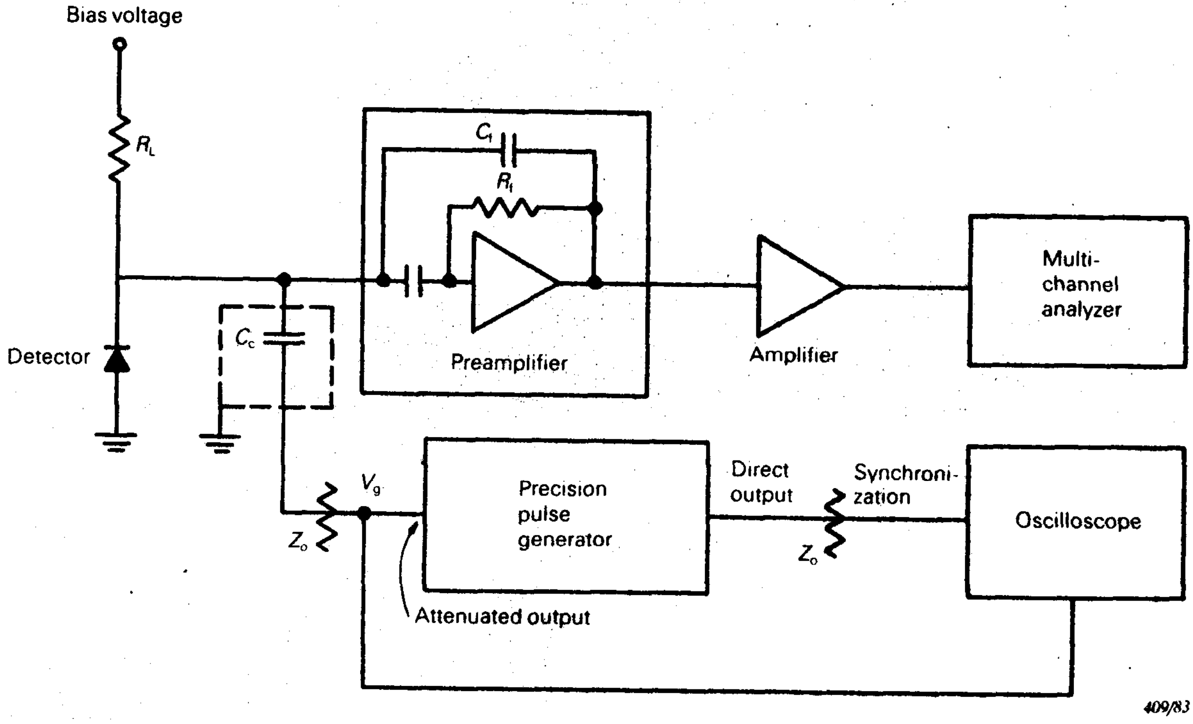

FIG. 1. - System configuration for spectral measurements.

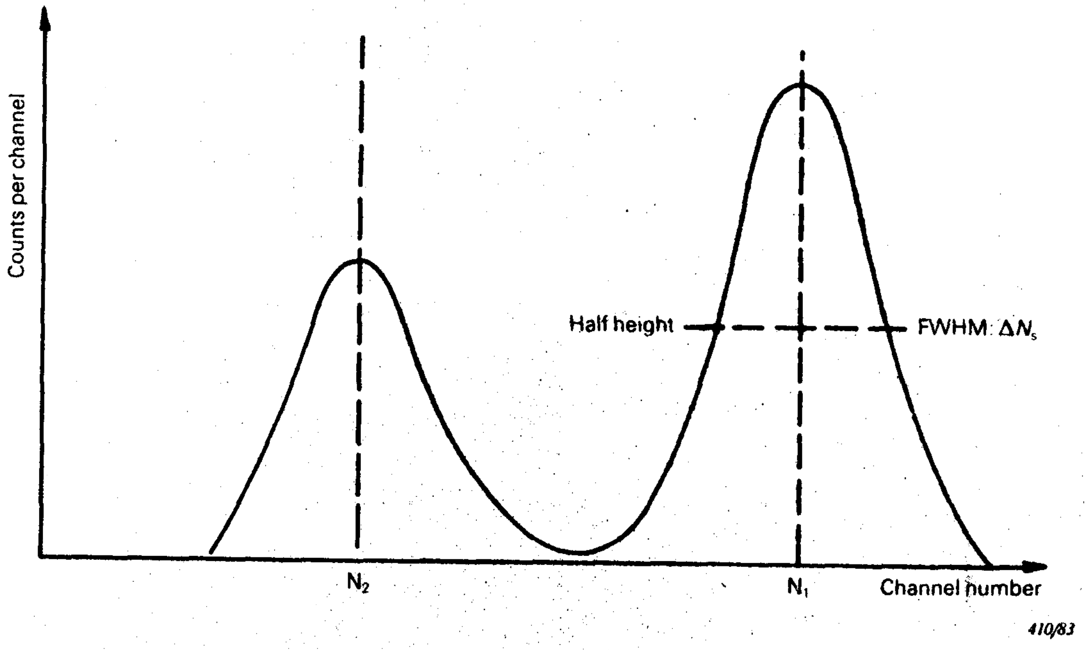

FIG. 2. - A typical spectrum.

A spectrum shall be acquired in which the peak to be measured has a FWHM of at least six channels and a peak channel count of at least 4 000 counts. At least one other peak should be located in the spectrum for the purpose of energy calibration. This may be a line of known energy from a source of ionizing radiation. Alternatively, it may be a line produced by a precision pulse generator. A typical spectrum for this measurement is shown in Figure 2, page 11.

The FWHM of the peak is measured in channels ΔN_S (interpolated). The channel location of the peak centre can be determined by the method described in Section Two of IEC Publication 340. The energy E_1 of the peak should be known and its channel location N_1 noted. If a second peak corresponding to energy E_2 is known, then the FWHM in energy units is given by:

$$\Delta E_S = \frac{E_1 - E_2}{N_1 - N_2} \Delta N_S \qquad (1)$$

If the peak corresponding to energy E_2 is produced by a precision pulse generator, then the pulse generator is calibrated by adjusting the attenuation of the output until pulses of voltage V_{p1} are shown to produce a peak of channel location N_1 on the multichannel analyzer. This is the same location as that of the peak of known energy E_1. Then a second peak is generated using pulses of voltage V_{p2}. The energy corresponding to this peak is given by $E_2 = V_{p2} (E_1 / V_{p1})$. The value of E_2 can then be used in equation (1) to find the FWHM in energy units ΔE_S. Energy calibration may also be accomplished by appropriate normalization of the pulser output. For example, the linear attenuator output of the pulser is set to a multiple of the numerical value of the peak energy E_1. Then a second (normalization) attenuator is adjusted until the output voltage is V_{p1}. This voltage is achieved when the output pulses produce a peak at channel location N_1 corresponding to energy E_1. The linear attenuator may then be set to the desired value of E_2, and the output voltage will be V_{p2}. The actual values of V_{p1} and V_{p2} do not need to be known since their relative values are given by the attenuator setting. If this method is employed, the precision pulse generator shall have an integral nonlinearity of less than 0.5%.

In recording information on energy resolution, the following shall be noted:

1) Incident particle type and energy.
2) Amplifier pulse shaping parameters (Δt, t_p, t_t) and type of pulse shaping utilized.
3) Detailed description of the detector including active area and sensitive depth.
4) System total noise FWHM with the detector connected and operating.
5) Detector operating conditions (bias, temperature, ambient atmosphere).
6) Detector-source geometry, including identification of the detector face on which the radiation is incident.
7) Count rate.
8) Procedure used in determining channel location and FWHM in fractional channels.

4.2 *Time resolution*

The measurement technique given here is recommended for its convenience and reproducibility. However, the results will be generally better than can be obtained when using charged particles. In the case of charged particles, plasma effects and the greater spatial dispersion of charge produced by long range particles will degrade the time resolution. The results obtained with this method should represent the best performance possible with a given detector-preamplifier timing system.

The timing characteristics of a detector-preamplifier system can be measured by exciting the detector with a light pulse from a laser diode pulser (LDP). A coincidence system, as in Figure 3, page 17, is used for this measurement. A start signal from the LDP and a stop signal from the detector under test are needed. A time-to-amplitude converter followed by a multichannel analyzer measures and records the time differences between the start and stop signals. The time spectrum obtained with the multichannel analyzer represents the distribution of these time differences. The FWHM and FWTM (full width at tenth maximum) of the peak measured at several energies should be stated to characterize the timing properties of the system. The energies selected should cover the operating range and should be separated by approximately equal energy intervals.

The signal from the detector preamplifier is routed through a fast shaping amplifier followed by a constant fraction discriminator. The constant fraction should be set at 20%. A shaping time delay equal to 1.1 times the pulse rise time (10% to 90%) shall be used. Shaping times should be adjusted to optimize the timing performance. (Shaping with no integration and a differentiation time constant somewhat greater than the preamplifier output signal rise time is usually optimum.)

The equivalent energy of the light pulses from the LDP shall be known. A vacuum chamber is used in which the detector may be rotated to face either the LDP or a ^{241}Am source. The precision pulse generator is first calibrated for the 5.48 MeV α line of ^{241}Am. Then the desired energy is selected with the pulser, and the LDP adjusted to produce the same signal amplitude. Typically, several timing measurements are made at energies ranging from ≈1 MeV to ≈100 MeV. The precision pulser output should be off while the timing measurement is being made.

Using this method, a timing peak should be obtained with a FWHM of at least six channels, and with at least 4 000 counts contained in the peak channel. Alternatively, if computer curve-fitting is used, determination of the FWHM within ±5% (90% confidence level) is adequate.

After calibrating the time axis with at least two calibrated delays, the FWHM and FWTM shall be measured and stated in units of nanoseconds. Measurements at three or more energies ranging from ≈1 MeV to ≈100 MeV, as obtained by adjustment of the Iris diaphragm (Figure 3), are recommended. (Quadrature subtraction can be used to determine the time resolution of the detector itself from the system time resolution that is measured.) The following parameters shall be stated for each measurement:

1) Spectral characteristics of the pulsed light.
2) Detector bias voltage.
3) Constant fraction discriminator setting and shaping time delay.

4) Differentiation time and rise time of the fast shaping amplifier.

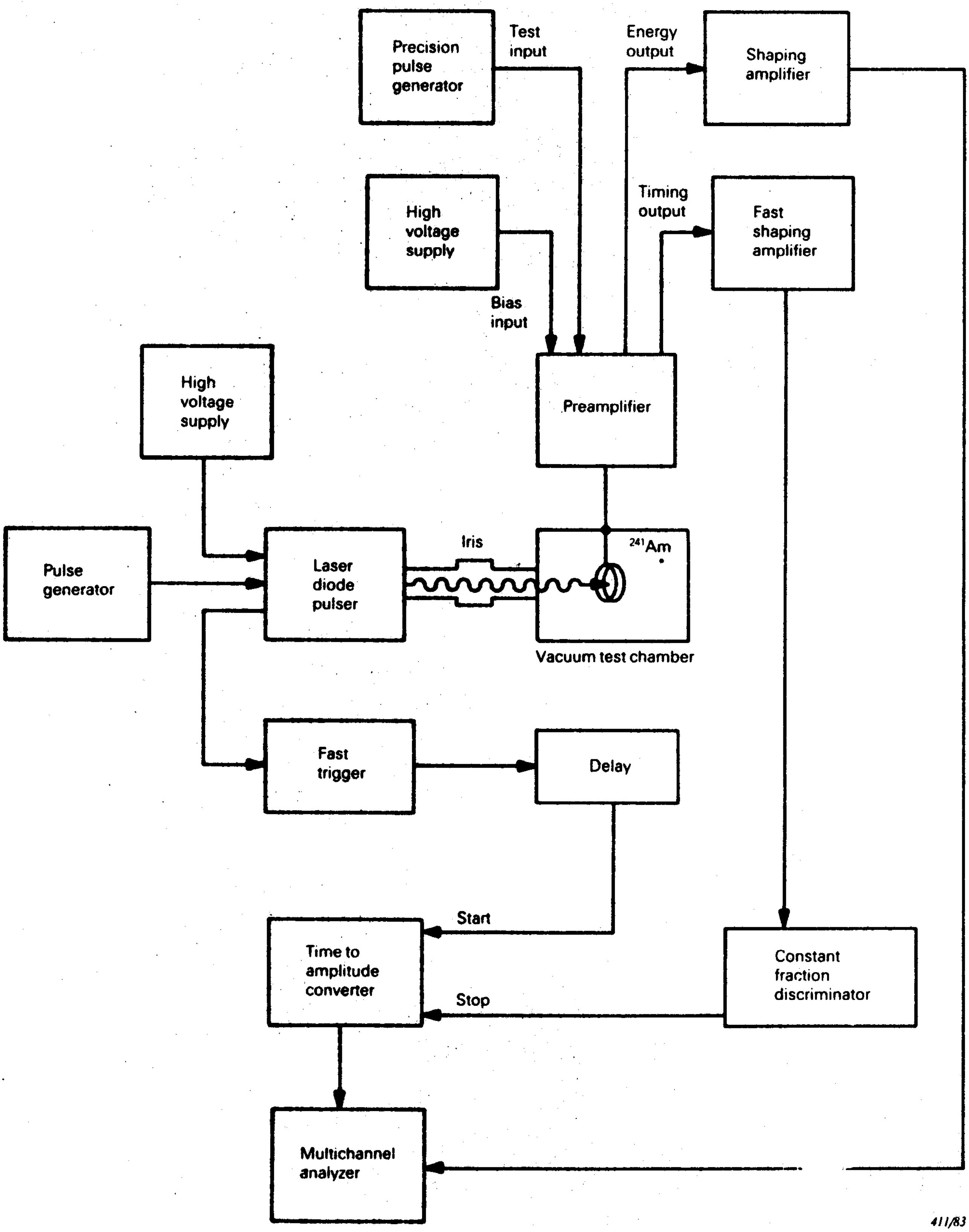

FIG. 3. – Time resolution measurement system.

4.2.1 *Detector electrical rise time*

Using the apparatus of Figure 4, a series of steps of V_p volts is applied to the detector. The value of V_p shall not exceed one-tenth of the band gap voltage, or one-tenth of the bias voltage, whichever is the smaller. The quadrature difference between the rise time of the preamplifier output signal with the detector connected and the preamplifier rise time is defined as the electrical rise time.

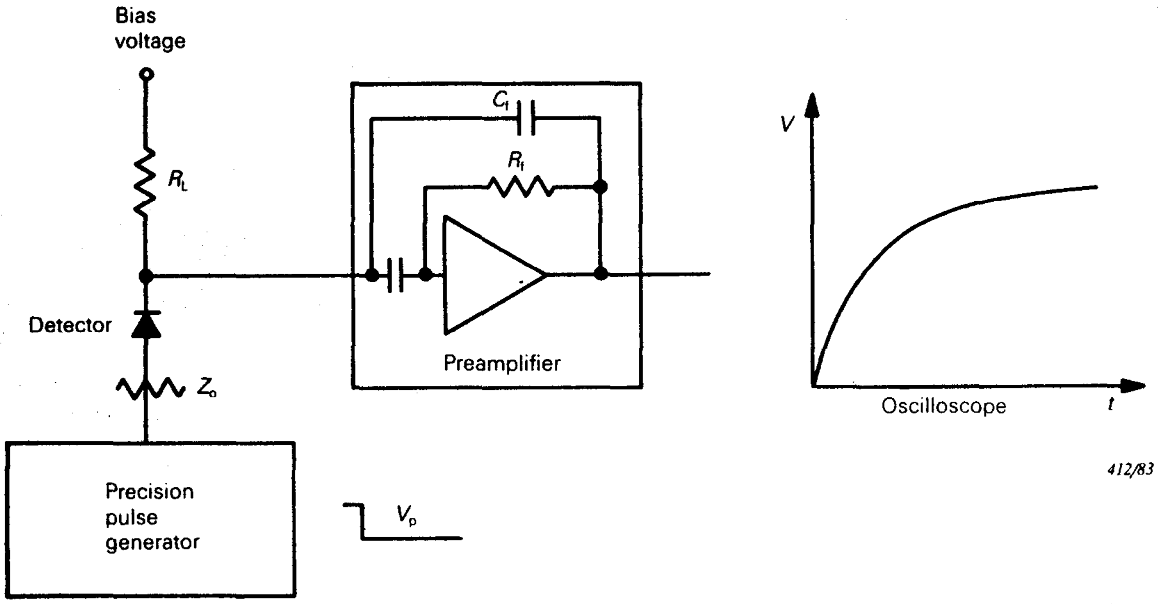

FIG. 4. - Detector electrical rise time measurement.

4.2.2 *Charge collection time*

Direct measurement of charge collection time t_c for one sign of charge carrier in relatively "slow" detectors can be made by using a monoenergetic source of short range particles and observing the signal pulse directly at the output of an integrating preamplifier. If the observed 10% to 90% output pulse rise time is t_o, while the rise time observed by injecting pulses into the preamplifier input from a precision pulse generator is t_r, then the detector charge collection time is given by:

$$t_c = \sqrt{t_o^2 - t_r^2} \qquad (2)$$

For this measurement to be significant, t_o and t_r shall differ by at least 20%.

The response of a fast detector is most easily measured by using a fast pulsed accelerator or a fast pulsed light source to generate a large number of hole-electron pairs in a detector and monitoring the resulting current pulse directly using a sampling oscilloscope.

In either case, it is essential to determine the detector electrical rise time (see Sub-clause 4.2.1) by separate measurements and to distinguish its effect from that due to carrier motion in the depletion layer.

Charge collection time data shall include details of the nature of the incident radiation, track orientation and position and amplifier rise time.

4.3 *Position, resolution and linearity of a position-sensitive detector*

One common type of position-sensitive detector is shown in Figure 5, page 23. This detector has one contact of relatively high resistivity which has one end grounded and the other end connected to a preamplifier input. The resistive contact acts as a current divider, and as a result, the output pulse height is proportional to the distance of the position of impact from the grounded end of the detector. Bias voltage is applied to the opposite contact.

Both position and energy measurements for this type of detector should be made using the system shown in Figure 6, page 23, (preferred method) or an equivalent system. As an alternative, commercially available analog pulse dividers may be used. Time constants and other settings should be optimized. The system, as it is used, shall be capable of simultaneously measuring position and energy. This is required since a system configured only for energy measurements may have measurably better resolution than a system configured for the simultaneous measurement of energy and position. An energy-only system may provide a useful measurement of the detector quality, but it is not fully representative of the detector performance in many applications.

Position resolution and linearity measurements are performed with a mask having slits in it placed in front of the detector face as shown in Figure 9, page 31. The slits are perpendicular to the direction along which position is measured. A minimum of five slits should be approximately uniformly distributed across the mask in front of the active region of the detector. A slit image shall be located at each end and near the middle of the useful active length of the detector because the deviation from linearity is usually largest at these positions. Sources of monoenergetic ionizing radiation shall be located in front of the mask in such a way that the radiation exposes regions of the detector to form an image of the slits on the detector surface.

The details of collimation, source location and geometry shall be such that the following conditions are met:

1) There is a one-to-one correspondence between the slits on the mask and the slit images on the detector.

2) The width of the image of each slit is small enough that it does not introduce any significant error into the position resolution measurements. (If any corrections are made for finite slit width, a simple quadrature subtraction is not adequate. Any correction shall not exceed 10% of the reported result.)

3) The error in determining distances between the slit images is small enough that it does not introduce any significant error into the position linearity measurement. (This usually requires placing slits as close to the detector surface as possible.)

4) The image of each outermost slit used shall be located within two slit widths of the ends of the useful active length of the detector.

A spectrum shall be acquired using the described methods. Each peak must have a FWHM of at least six channels with a minimum of 4 000 counts in the peak channel. Position linearity and resolution are determined from this spectrum.

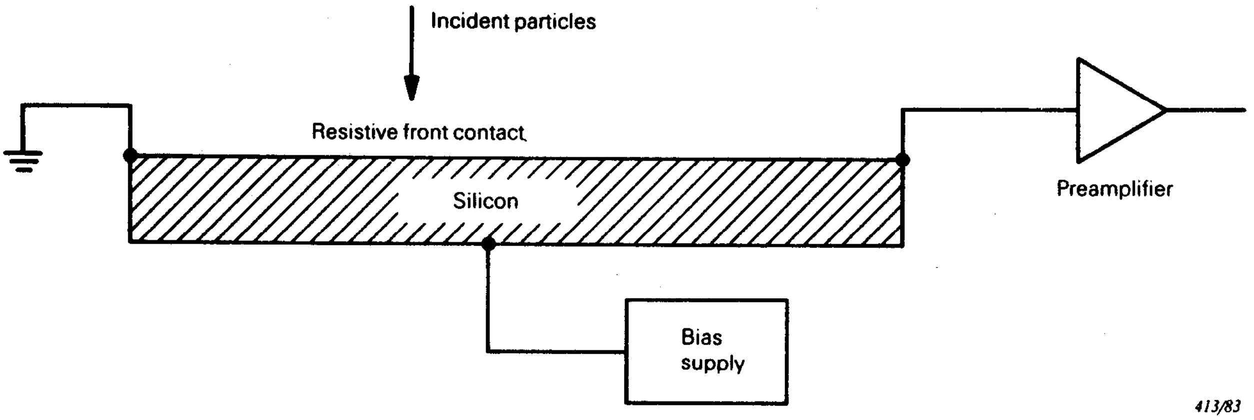

FIG. 5. - Position-sensitive detector.

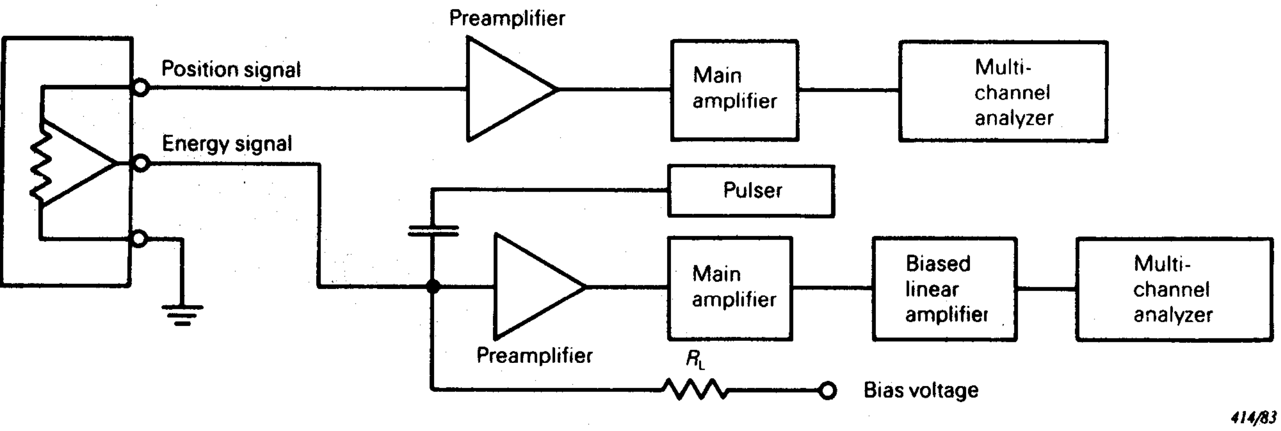

FIG. 6. - System for position-sensitive detector measurements.

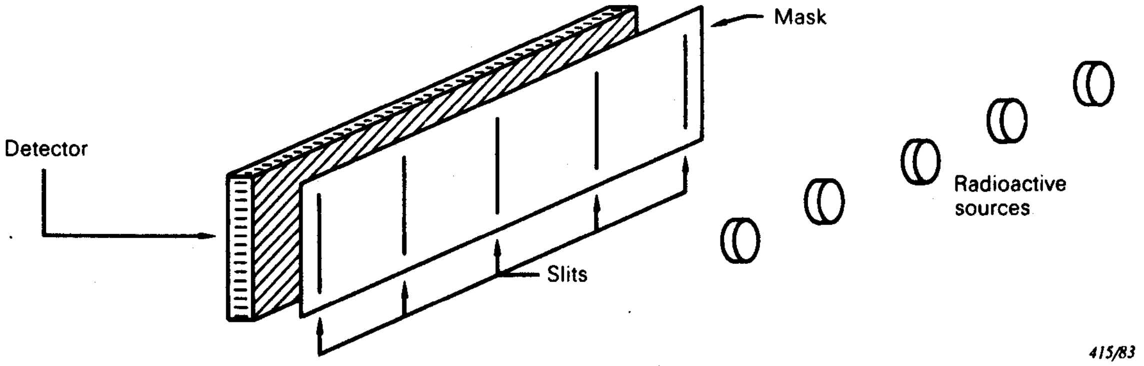

FIG. 7. - Apparatus for position measurements.

The integral nonlinearity (in position) of a position-sensitive detector is defined as the maximum positional deviation from linearity expressed as a percentage of the total length over which the measurement is made. The deviation from linearity should be measured for each slit image, and the integral nonlinearity of the detector is determined from the largest of these values.

Let the channel number be represented by S and the peak channel numbers by S_0, S_1, $S_2, \ldots S_i, \ldots S_m$, where S_0 and S_m are the smallest and largest peak channel numbers respectively. Let $D\,(D_0, D_1, D_2 \ldots D_m)$ be the perpendicular distance measured from the first slit image (at the grounded end of the detector). The distances from the first slit image to successive slit images are represented by $D_1, D_2, \ldots D_i, \ldots D_m$.

Set $D_0 = 0$, and let D_m be the distance between the two outermost slits used in the measurement. A straight line is then fitted to the set of points (D_0, S_0), (D_1, S_1), (D_2, S_2) … $(D_i, S_i) \ldots (D_m, S_m)$ by the method of least squares. Let ΔD_{max} be the maximum difference between any value of D_i and the corresponding value of D on the fitted line at the point where $S = S_i$. The integral nonlinearity of the detector is given by:

$$L_p = \frac{\Delta D_{max}}{D_m} \tag{3}$$

Position resolution is calculated for each slit image. Given the FWHM of a peak in channels ΔN_p, the position resolution in units of length ΔD_p is given by:

$$\Delta D_p = \frac{D_m}{S_m - S_0} \Delta N_p \tag{4}$$

If one value of positional resolution is given to characterize the entire detector, it shall be the largest FWHM value obtained for any slit image. Record the same information with this measurement as requested for the energy measurement in Sub-clause 4.1.

The following information shall be supplied with the results of this linearity measurement:

1) Total active length of the detector.
2) Useful active length of the detector.
3) Time constants (shaping time characteristics) used for energy and position measurements.
4) Detailed description of the detector including sensitive depth and detector geometry.
5) Operating conditions.
6) Incident particle type and energy.

5. Noise measurement

5.1 *Noise measurement by pulse height distribution (preferred method)*

5.1.1 *Measurement with radioactive source calibration*

The total noise contribution to spectral broadening (including detector leakage current) can be measured by determining the FWHM of a peak produced with a precision pulse generator.

The equipment shall be configured as shown in Figure 1, page 11. The preamplifier pulse shaping shall be quasi-Gaussian with a Δt of 3 µs. Alternatively, other shaping suitable for the detector may be used, but the shaping characteristics shall then be clearly stated and the same as those used to specify energy resolution. A simple method for system calibration is similar to that described in Sub-clause 4.1 using a source of monoenergetic ionizing radiation and a precision pulse generator. However, the radiation (of known energy E_1) need only be counted until the peak location N_1 is accurately known. The source is then removed, and the pulser is adjusted to generate a peak at this same location. A second peak, equivalent to energy E_2 at location N_2 is generated with E_2 determined from the calibration as in Sub-clause 4.1.

The spectrum of the second pulse generator peak shall be accumulated until it reaches 4 000 counts in one channel. The width shall be at least six channels at FWHM. However, a lesser number of counts may suffice if computer fitting that determines the FWHM to within ±5% (90% confidence level) is employed. The total noise resolution is determined from the width of this peak in channels ΔN_T by:

$$\Delta E_T = \left[\frac{E_1 - E_2}{N_1 - N_2}\right] \Delta N_T \qquad (5)$$

The separation of the peaks should be at least three times the FWTM.

5.1.2 *Measurement with capacitor and pulse generator calibration*

An alternative to the method of Sub-clause 5.1.1 uses a pulse generator with a calibrated capacitor to introduce a known quantity of charge with each pulse to the preamplifier input. This leads directly to the determination of noise linewidth in units of charge. If this method is to be used, a calibrated capacitor C_c is connected to the preamplifier input in series with a precision pulse generator. The capacitor C_c should preferably be of the three-terminal type; the capacitance is measured between two insulated terminals, and the third terminal is grounded. A highly accurate measurement of the capacitance between the two insulated terminals can be obtained with a capacitance bridge, and this capacitance is invariant with external circuit connections. The pulse generator should provide signals of the form shown in Figure 8, page 29, where the rise time t_r is no more than 20% of the main amplifier differentiating time constant and the decay time constant τ_d is such that the pulse V_p does not drop more than 2% in a time equal to the differentiating time constant of the system pulse shaping network. In addition, the equivalent input capacitance of the integrating preamplifier shall be not less than 100 C_c.

Under these conditions the charge injected per pulse from the pulse generator is $V_p C_c$ coulombs to within about 1%. (If the stated conditions are not satisfied, a calculation can be made to determine the quantity of charge actually injected by each pulse.) With all elements of the system operating within their linear range, two settings of the pulse generator, corresponding to voltages V_{p1} and V_{p2}, should result in a spectrum consisting of two separated peaks centred at channels N_1 and N_2 as shown in Figure 4, page 19. The system gain and pulse amplitudes must be such that the full width at half maximum (FWHM) ΔN_T of each peak is at least six channels.

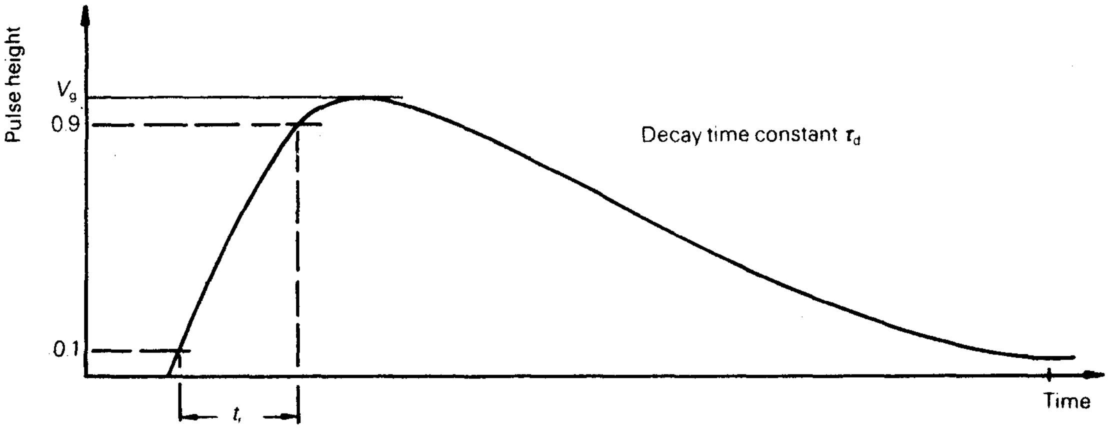

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FIG. 8. - Precision pulse generator waveform.

The system total noise linewidth (FWHM), in coulombs, is given by:

$$\Delta Q_T = \frac{V_{p1} - V_{p2}}{N_1 - N_2} C_c \Delta N_T \qquad (6)$$

with ΔN_T being determined from the wider of the two peaks.

5.2 *Noise measurement by oscilloscope and true root-mean-square voltmeter*

An alternative method of measuring noise employs the system shown in Figure 9, page 31. It is similar to the system used for pulse height distribution measurements (Figure 1, page 11), but it differs in that a true r.m.s. voltmeter replaces the multichannel analyzer. This method may use either a radioactive source or capacitor and pulse generator calibration.

If this method is to be accurate, two conditions must be fulfilled.

1) The voltmeter shall have a flat frequency response over the entire amplifier bandwidth, and a true r.m.s. readout. (A suggested minimum 3 dB bandwith is 10 MHz.)

2) The amplifier incremental gain shall be constant down to well below the noise level (e.g. a biased amplifier shall not be used).

An estimate of the noise can be obtained by means of an effective voltmeter. In this case, $e_{no} \simeq 1.12\ e_{eff}$, where e_{eff} is the voltmeter reading.

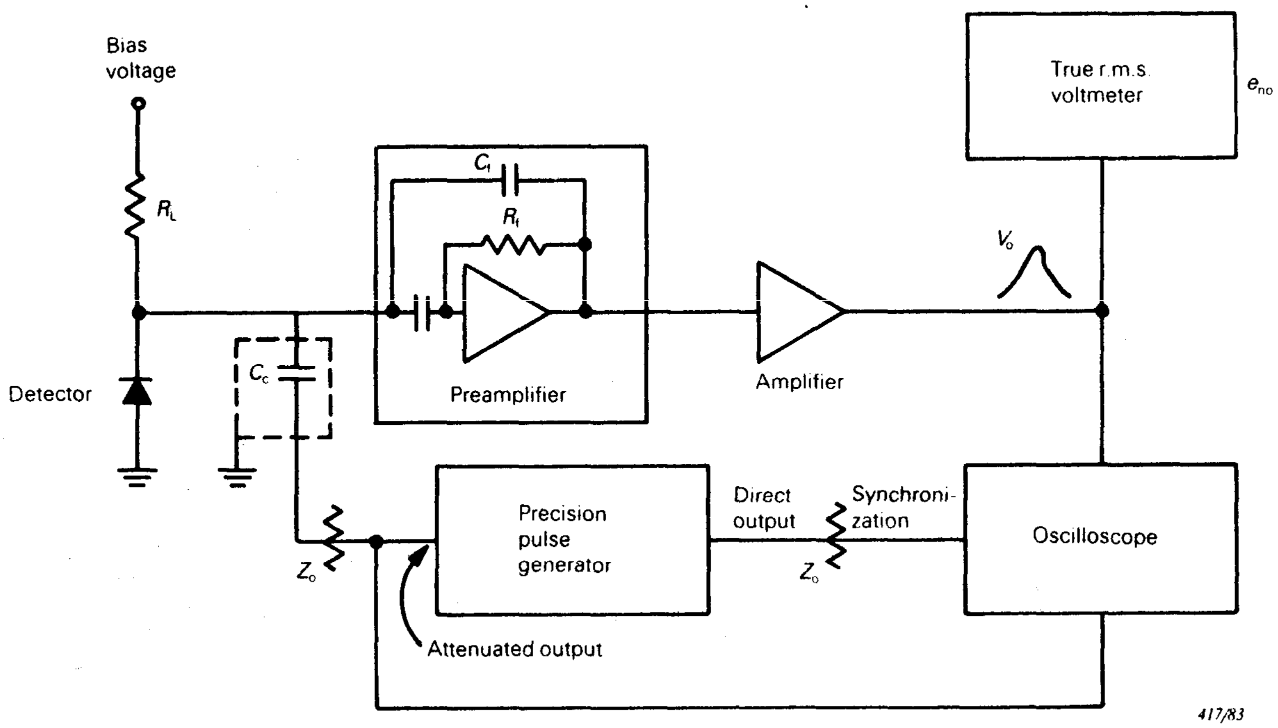

FIG. 9. - Noise measurement by oscilloscope and true r.m.s. voltmeter.

5.2.1 *Measurement with radioactive source calibration*

The detector is exposed to a source which has a prominent, easily resolvable line of known energy E. After the system gain has been set to a convenient level, the output pulse amplitude V_0 is read from the oscilloscope for pulses corresponding to energy E. The source is then removed, and the r.m.s. voltage e_{no} is read from the voltmeter. The total system noise FWHM is given by:

$$\Delta E_T = 2.355 \frac{E}{V_0} e_{no} \tag{7}$$

5.2.2 *Measurement with capacitor and pulse generator calibration*

A pulse generator is used with a calibrated capacitor C_c, as in Sub-clause 5.1.2, to introduce a known quantity of charge with each pulse into the preamplifier input. After the system gain is set to a convenient level, pulses of amplitude V_p are applied to the calibrated capacitor. The system output pulse amplitude V_0 is read from the oscilloscope. The pulse generator output is switched off, and the r.m.s. noise voltage e_{no} is read from the voltmeter. The total system noise FWHM (in units of charge) is given by:

$$\Delta Q_T = 2.355 V_g C_c \frac{e_{no}}{V_0} \tag{8}$$

5.3 *Measurement of electronic noise with the detector removed*

The electronic noise linewidth FWHM can be determined by the methods of Sub-clauses 5.1 and 5.2 after disconnecting the detector from the circuit and substituting for it a suitable capacitor which has been shown not to contribute noise and which is of capacitance substantially equal to that which the detector exhibited under test conditions (see Sub-clause 7.2).

If radioactive source calibration is used, then it shall be performed before the detector is removed. Care shall be taken not to change the system gain before the measurement is made. The capacitor and pulse generator calibration may be performed with either the detector or the substituted capacitor in place.

The noise FWHM is determined in number of channels, units of charge or in units of energy according to the methods of Sub-clauses 5.1 and 5.2, and the symbols used are ΔN_E, ΔQ_E or ΔE_E respectively. These values represent the electronic noise without the detector noise contribution.

5.4 *Determination of detector contribution to noise and resolution*

In Clauses 4 and 5, methods are given to determine energy resolution (ΔN_S, ΔE_S), total system noise (ΔN_T, ΔQ_T, ΔE_T) and electronic noise other than detector noise (ΔN_E, ΔQ_E, ΔE_E). These quantities are expressed in channels (ΔN), and units of charge (ΔQ), and in units of energy (ΔE), respectively.

Since all of these spectral broadening effects add in quadrature, the following quantities of interest may be calculated for Gaussian or quasi-Gaussian distributions:

1) The detector contribution to spectral broadening attributable to factors other than noise, ΔN_0 or ΔE_0.

$$\Delta N_0 = \sqrt{\Delta N_S^2 - \Delta N_T^2} \qquad (9)$$

or

$$\Delta E_0 = \sqrt{\Delta E_S^2 - \Delta E_T^2} \qquad (10)$$

2) The contribution to spectral broadening of detector noise alone ΔN_D, ΔQ_D, or ΔE_D.

$$\Delta N_D = \sqrt{\Delta N_T^2 - \Delta N_E^2} \qquad (11)$$

or

$$\Delta Q_D = \sqrt{\Delta Q_T^2 - \Delta Q_E^2} \qquad (12)$$

or

$$\Delta E_D = \sqrt{\Delta E_T^2 - \Delta E_E^2} \qquad (13)$$

5.5 *Noise linewidth (FWHM) as a function of amplifier time constants*

Information related to the detector noise spectrum can be obtained from the noise linewidth FWHM as a function of the amplifier time constants. The method of Sub-clause 4.1 is employed with quasi-Gaussian pulse shaping. The noise linewidth FWHM should be plotted versus Δt for a number of values of detector bias voltage. In quoting the results, the series equivalent noise resistance of the input element of the preamplifier should be given (see IEC Publication 340).

6. Sensitivity to ambient conditions

In performing the following measurements, the manufacturer's specifications should not be exceeded or permanent damage to the device may result.

For certain tests it may be appropriate to test the detector before and after exposure to specified conditions rather than during exposure. Other tests may be performed during exposure. When test results are quoted, it should be clearly stated whether they were obtained during exposure or before and after exposure. The limits of reproducibility of the measurements should be stated with the results.

6.1 *Atmospheric sensitivity*

The detector shall be mounted in a chamber in which it can be tested while exposed to vacuum or to various gases under specific conditions of pressure, temperature and humidity. Such conditions may include, for example, dry oxygen at standard temperature and pressure. Other appropriate conditions may be specified for particular applications.

In each environment, sufficient time shall be allowed to enable the detector characteristics to reach equilibrium. Alternatively, the time spent in each environment shall be recorded. Under each set of ambient conditions, the appropriate tests described in Sub-clauses 4.1, 4.3, and 4.4 may be repeated.

It should be noted that certain environments may be very harmful to many detectors. Bottled gas has been known to become contaminated with harmful substances such as certain acids. Some desiccants may give off a residual acid. Various solvents and cleaning compounds may evolve harmful vapours. Ammonia vapour and other reducing atmospheres may be harmful.

6.2 *Vacuum thermal cycle test*

The ability of a device to withstand vacuum thermal cycling without degradation is important for certain applications. A temperature cycle over a specified range with a vacuum of 10^{-4} Pa ($\simeq 10^{-6}$ mm Hg) is suggested.

The noise of a detector should first be measured at 20 °C. Then the detector should be taken through the required thermal cycle. Noise values at 20 °C, at maximum temperature and at minimum temperature should be recorded. Finally, the temperature of the detector should be returned to 20 °C and the noise measured again. The final measured noise value should not differ from the initial noise value at 20 °C by more than the stated limits of reproducibility in in order for the detector to pass this test.

The detector may be taken through a thermal cycle while under vacuum with no applied bias voltage. The detector should have a noise measurement at 20 °C with the same bias voltage both before and after such a thermal cycle. Again, the two noise measurements should not differ by more than the stated limits of reproducibility for the detector to pass this test.

6.3 *Mechanical and environmental tests*

Detectors may be tested both before, during and after any specified mechanical, thermal or other environmental exposure. All of the tests indicated in Sub-clauses 4.1, 4.3, 4.4 and 5.6 may be performed. As a minimum the noise and leakage current should be measured before and after such exposure. Unless other specifications suitable for the particular application are stated, the measured characteristics of the detector should not change by more than the stated limits of reproducibility for it to pass such a test.

In certain cases, such as long-term exposure to a vacuum environment, it may be necessary to perform electrical tests during the exposure period as well as before and after it.

6.4 *Light sensitivity*

Most detectors are light sensitive and should be used and tested in the dark. Some detectors are constructed in such a way that they are relatively insensitive to light. The light sensitivity of a detector should be specified as that percentage increase in system noise which results from moving the detector from total darkness to specific conditions of light exposure.

The recommended condition of light exposure shall be achieved by placing the detector 45.0 cm away from the standard lamp with the face of the detector perpendicular to a line connecting the lamp and the detector. The standard lamp shall be a 250 W tungsten filament quartz-halogen bulb with a colour temperature of 3 000 K.* A filament current of 2.08 ± 0.05 A d.c. shall be maintained. Test conditions shall be provided in which reflected light and contribution of light from other sources are minimized.

It should be noted that the noise increase observed for a detector with some light sensitivity can be much greater if the light is modulated rather than constant in intensity. This is particularly relevant for detectors exposed to fluorescent lighting. Detectors to be used under conditions of modulated light should be tested for sensitivity to such light.

Other conditions of light exposure may be used as required for certain applications. Such conditions should be stated if a value of light sensitivity is given. Note that light intensity above a certain level will significantly heat the detector and result in thermal effects.

6.5 *Radiation damage measurements*

Following irradiation, properties of the detector may be affected and each test may have to be repeated. To obtain meaningful data, it is important that all the following be recorded:

1) Test data obtained before irradiation.
2) Type and energy of radiation, flux and fluence.
3) Detector temperature, bias voltage and ambient conditions during irradiation.
4) Time between termination of irradiation and commencement of tests, and detector conditions in the intervening period.

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* It shall have the same bulb and filament configurations and meet all other specifications of ANSI designation ENH or equal.

7. Other measurements

7.1 *Current-voltage characteristics*

A point-by-point measurement is made of the reverse bias leakage current as a function of the detector voltage V_b at a constant temperature (see Figure 10).

Both the points corresponding to successively increasing and successively decreasing voltage should be recorded. The voltage changes should be made slowly enough to exhibit any hysteresis effects.

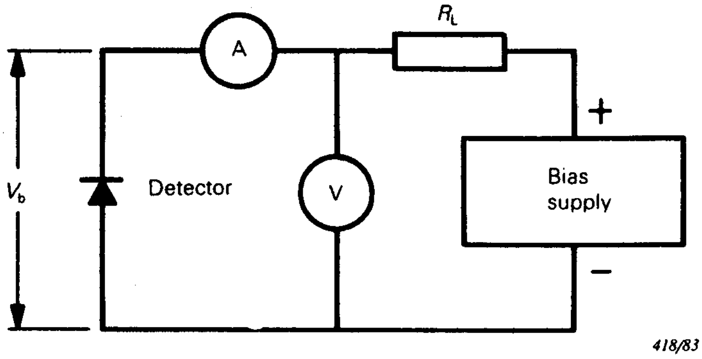

FIG. 10. - Detector current-voltage characteristic measurement.

7.2 *Dead layer energy loss*

A beam of monoenergetic heavy ionizing particles is caused to impinge upon a detector whose dead layer is to be measured. The amount of energy lost in the dead layer region shall be such a small part of the total energy that there is no significant spectral broadening. The particles shall be collimated to a semi-angle not exceeding 5° and oriented so that the incident particles enter the detector normal to the surface. A spectrum is then obtained. The detector is subsequently rotated by an angle θ and another spectrum is obtained. Using the reference pulse generator, the energy origin of the multichannel analyzer and hence the energy difference δE between the two spectra can be determined. From this difference, the effective energy loss for the particles used in the test may be determined. The 5.48 MeV α particles emitted by ^{241}Am are suggested as a standard, although other particle types and energies may be used.

If the specific energy loss within the dead layer is essentially constant, the energy lost in the dead layer by particles at normal incidence is given by:

$$\text{DLLN} = \delta E \frac{\cos\theta}{1-\cos\theta} \tag{14}$$

where:

DLLN = dead layer energy loss at normal incidence

δE = energy difference, in MeV, between measurements at normal incidence and after a rotation through angle θ

θ = angle of rotation of detector for non-normal incidence of particles (45° is a recommended value for θ)

Since the dead layer energy loss may depend on the detector bias voltage, this voltage should be stated. For transmission detectors, the measurement shall be performed for both the entrance and exit faces. The method is applicable only to charged-particle detectors with a depletion depth exceeding the incident particle range and if the energy resolution permits.

7.3 *Sensitive area*

While monitoring the detector leakage current, the surface is explored with a small light spot. The edge of the sensitive region can be defined as that boundary beyond which the photocurrent decreases by approximately 10%. The light spot diameter shall be small compared with the dimensions of the sensitive area and the light intensity such that the photocurrent is large compared to the leakage current. For detectors having an opaque front window, the edge of the sensitive region can be found by using a collimated beam of monoenergetic heavy charged particles and defining the boundary as that region beyond which the FWHM of the spectral peak doubles in value.

The sensitive area, without regard to delineation, may be measured by exposing the detector to a known flux of heavy charged particles and measuring the counting rate with and without a collimator of known dimensions.

7.4 *Detector thickness (transmission detectors)*

A radioactive source is used to provide a narrow collimated beam of monoenergetic photons (X-rays or low energy γ-rays). Provision shall be made to determine the location of the charged-particle detector in this beam. The beam shall also be incident upon a detector which is part of a low energy photon spectroscopy system. A high resolution detector is needed to minimize the effect of scattered radiation on this measurement. The intensity of the radiation, from the line of interest, incident on the photon detector is measured both with and without the presence of the charged particle detector.

Thickness is then determined from the attenuation by the charged-particle detector of the specific photon energy employed. This technique may be used to measure thickness uniformity by using a narrow collimated beam. The matching of photon energy to charged-particle detector thickness should be such that at least 15% but no more than 85% attenuation is achieved. The 6.4 keV, 14.4 keV and 122 keV lines from ^{57}Co are frequently useful for this measurement. It shall be noted that the X-ray attenuation technique measures the total effective detector thickness and not the detector sensitive thickness.

This thickness measurement can be performed non-destructively on finished devices. During the manufacturing process, simpler techniques are feasible.

7.5 *Capacitance-voltage characteristics*

The capacitance of a detector as a function of detector bias can be measured by using an a.c. bridge. The bridge should operate in the range 10^3 Hz to 10^5 Hz. At each value of applied bias the peak-to-peak a.c. signal amplitude applied to the detector shall not exceed 10% of the d.c. bias voltage or 10% of the band gap voltage, whichever is the smaller. The detector temperature, bias voltage and environment shall be recorded.

A log-log plot may be used to display the capacitance-voltage characteristics. Series resistance, possibly resulting from undepleted base material in the diode, can lead to significant errors in the capacitance values obtained by this technique. This measurement tends to be more susceptible to error from surface effects at low bridge frequencies. Errors caused by stray capacitance can be minimized by using a three-terminal measurement.

APPENDIX A

SYMBOLS AND GLOSSARY

A1. Symbols

C = electrical capacitance

C_c = calibrated capacitor used to couple a pulse generator to circuit under test

C_{eff} = effective input capacitance of a preamplifier

C_f = feedback capacitance in the charge-sensitive loop of a preamplifier

C_t = total capacitance at preamplifier input

D = perpendicular distance from the first slit image measured along the surface of a position-sensitive detector. (The image is formed by ionizing radiation passing through a mask with slits used to measure positional linearity. The first slit is at the grounded end of the detector.)

D_i = distance D between the images of the first slit and the ith slit measured along the surface of a position-sensitive detector. (The index i ranges from $i = 0$ to $i = m$ such that $D_0 = 0$ and D_m is the distance between the two outermost slits used.)

δE = energy difference in dead layer measurement

Δ = full width at half maximum (FWHM) of a spectral peak

ε = the average energy required to form one hole-electron pair in a semiconductor detector

e = the charge of the electron

e_{no} = equivalent root-mean-square noise voltage referred to the preamplifier input

L_p = integral nonlinearity in position of a position-sensitive detector

N, N_i = channel number used to represent energy loss in detector of energy E_i

Q = electric charge

R = electrical resistance

R_L = detector load resistor

S = channel number for a multichannel analyzer spectrum obtained to check the positional resolution and linearity of position-sensitive detectors

S_i = peak channel number of the ith position peak generated by a position-sensitive detector when used with a mask with slits. (The index i ranges from $i = 0$ to $i = m$)

T = absolute temperature (K)

t = time

t_c = charge collection time in a detector

t_o = observed detector rise time due to the combined effects of the charge collection time and electronic rise time

t_f = pulse fall time (90% to 10% of its peak value)

t_p = peaking time of a pulse

t_r = pulse rise time (10% to 90% of its peak value)

t_t = tailing time of a pulse

τ = time constant

τ_d = time constant for decay of a pulse

V = voltage

V_a = amplitude of pulse amplifier output

V_b = detector bias (operating) voltage

V_g, V_{gi} = output voltage of precision pulse generator, and that corresponding to energy E_i

V_o = amplitude of the voltage output signal of an amplifier during measurement of amplifier linearity

ΔD_{MAX} = maximum value observed for the difference between a value of D_i and the value of D at the point (D_i, S_i) on the line fitted to the set of points (D_i, S_i)

ΔD_p = FWHM of the position resolution in units of length
ΔE_A = FWHM, expressed in units of energy, due to amplifier noise
ΔE_D = FWHM, expressed in units of energy, due to detector noise
ΔE_E = FWHM, expressed in units of energy, due to electronic noise without the detector noise contribution
ΔE_0 = FWHM, expressed in units of energy, due to all factors other than electric noise
ΔE_S = FWHM, expressed in units of energy, derived in spectral energy resolution measurement
ΔE_T = FWHM, expressed in units of energy, due to the combined effect of detector and amplifier noise
ΔN_A = FWHM, expressed in channels, due to amplifier noise
ΔN_D = FWHM, expressed in channels, due to detector noise
ΔN_E = FWHM, expressed in channels, due to electronic noise without the detector noise contribution
ΔN_0 = FWHM, expressed in channels, due to all factors other than electric noise
ΔN_P = FWHM, expressed in channels, of a peak generated from the position signal of a position sensitive detector
ΔN_S = FWHM, expressed in channels, of an absorbed spectral peak used for energy resolution determination
ΔN_T = FWHM, expressed in channels, due to the combined effect of detector and amplifier noise
ΔQ_A = FWHM, expressed in units of charge, due to amplifier noise
ΔQ_D = FWHM, expressed in units of charge, due to detector noise
ΔQ_E = FWHM, expressed in units of charge, due to the electronic noise without the detector noise contribution
ΔQ_T = FWHM, expressed in units of charge, due to the combined effect of detector and amplifier noise
Δt = duration of a pulse; the time interval between the half amplitude points of a pulse
ΔX_S = FWHM for monoenergetic incident radiation, expressed in channels, including all spectral broadening effects
E, E_i = energy of a particle or radiation (or radiation having specific energy, E_i, where i is an integer, 1, 2, . . .)
ΔV_e = a voltage difference signal related to the nonlinearity of an amplifier
V_p, V_{pi} = amplitude of the voltage step impressed on a calibrated capacitor C_c by the pulse generator, corresponding to energy E_i
X, X_i = channel number, of channel corresponding to energy E_i
Z_0 = characteristic impedance

A2. Glossary

Active dimension (of a position-sensitive detector)

A dimension (i.e. length, width) of that region of a position-sensitive detector which is depleted.

Avalanche breakdown (of a junction)

A breakdown caused by the cumulative multiplication of charge carriers in a semiconductor under the action of a strong electric field which causes some charge carriers to gain enough energy to liberate new hole-electron pairs (field-induced impact ionization) (IEV 391-10-51).

Band gap

The difference in energy between the energy level of the bottom of the conduction band and the energy level of the top of the valence band.

Baseline (at pulse peak)
The instantaneous value that the voltage would have had at the time of the pulse peak in the absence of that pulse. (IEC Publication 340).

Bias (of a semiconductor radiation detector)
Synonymous with bias voltage.

Bias voltage (of a semiconductor radiation detector)
The voltage applied to the detector to produce the electric field to collect the signal charge (IEC Publication 340).

Biased linear amplifier
An amplifier giving essentially zero output for all inputs below a threshold and having constant incremental gain for all inputs above the threshold up to a specified maximum amplitude.

Bias resistor (of a semiconductor radiation detector)
The resistor through which bias voltage is applied to a detector (IEC Publication 340).

Blocking contact (of a semiconductor radiation detector)
That contact from which depletion proceeds into the semiconductor material under conditions of reverse bias.

Breakdown (of a reverse biased junction)
Transition from a state of high dynamic resistance to a state of substantially lower dynamic resistance for increasing magnitude of reverse voltage (IEV 391-10-50).

Breakdown region (of a semiconductor diode characteristic)
That entire region of the voltage-current characteristic beyond the initiation of breakdown for increasing magnitude of reverse current (IEC Publication 759).

Breakdown voltage (of a semiconductor diode)
The voltage measured at a specified current in the breakdown region (IEC Publication 759).

Capacitance (of a semiconductor radiation detector)
The capacitance between terminals of the detector as measured with small signals under specified conditions of bias and frequency (IEC Publication 340).

Channel, surface (of a semiconductor radiation detector)
A thin region at a semiconductor surface of p- or n-type conductivity created by the action of an electric field; e.g. that due to trapped surface charge.

Channelling, lattice (in a semiconductor radiation detector)
A phenomenon that results in a crystallographic directional dependence of the rate of energy loss of ionizing particles.

Charge carrier (abbreviation: carrier)
In a semiconductor, a free conduction electron or a mobile hole (IEV 391-10-53).

Charge collection time (of a semiconductor radiation detector)
By convention the time interval for the integrated current due to the charge collected in the semiconductor detector, after the passage of an ionizing particle, to increase from 10% to 90% of its final value (IEV 391-10-59).

Clip, clipping (jargon)
A limiting operation such as 1) use of a high-pass filter (see differentiated), or 2) a non-linear operation such as diode limiting of pulse amplitude.

Constant fraction discriminator

A pulse amplitude discriminator in which the threshold for acceptance of a pulse is a constant fraction of the peak amplitude of the pulse.

Note. – Its purpose is to produce an output pulse delayed with respect to the input pulse by a time interval essentially independent of the input pulse amplitude (IEC Publication 340).

Crest factor (of an average reading or root-mean-square voltmeter)

The ratio of (1) the peak voltage value that an average reading or root-mean-square voltmeter will accept without overloading to (2) the full scale value of the range being used for measurement (IEC Publication 340).

Cross-over time (of a pulse)

The instant at which the waveform of a bipolar pulse passes through a designated level (IEC Publication 340).

Cross-over walk (of a pulse)

The variation of the cross-over time for some variable, such as amplitude (IEC Publication 340).

CR-RC shaping

The pulse shaping present in an amplifier that has a simple high-pass filter and a low-pass filter, each consisting of a capacitor and a resistor, with the filters, separated by impedance isolation.

Note. – This definition is for use with this document.

Dead layer (of a semiconductor detector)

An inactive region (layer) in which the energy absorbed from the passage of monoenergetic charged particles does not significantly contribute to the resulting full energy peak (IEV 391-10-55).

Decay time constant

The time for a true single-exponential waveform to decay to $1/e$ of the original step height (IEC Publication 340).

Depletion layer (in a semiconductor detector)

A layer of a semiconductor detector which constitutes its sensitive volume. Most of the energy lost by the particles in this region can contribute to the resulting signal.

Depletion region (in a semiconductor)

A region in which the charge-carrier charge density is insufficient to neutralize the net fixed charge density of ionized donors and acceptors. In a diode-type semiconductor radiation detector the depletion region is the sensitive region of the device (IEC Publication 340).

Depletion voltage (of a semiconductor radiation detector)

Synonymous with total depletion voltage.

Differential dE/dx *semiconductor detector*

A transmission semiconductor detector in which the thickness of the depletion layer is small compared to the range of the incident particles in the semiconductor material (IEV 391-09-48).

Differentiated pulse

A pulse that is passed through a high-pass network, such as a CR filter (IEC Publication 340).

Diffused junction semiconductor detector

A semiconductor detector in which the P-N or N-P junction is produced by an impurity of one type into a semiconductor of opposite type.

Note. – The first letter P or N designates the type of the diffused impurities (IEV 391-09-43).

DLLN
Dead layer energy loss at normal incidence.

Energy resolution (FWHM) (of a semiconductor radiation detector)
The detector's contribution (including detector leakage current noise), expressed in units of energy, to the FWHM of a pulse height distribution corresponding to an energy spectrum (IEC Publication 340).

Energy resolution (per cent) (of a semiconductor radiation detector)
One hundred times the energy resolution divided by the energy for which the resolution is specified (IEC Publication 340).

Equivalent noise resistance referred to input (of a linear amplifier or preamplifier)
That value of resistor which when applied to the input of a hypothetical noiseless amplifier with the same gain and bandwidth would produce the same output noise.

Fixed fraction discriminator (see *constant fraction discriminator).*

Full width at half maximum (FWHM)
In a distribution curve comprising a single peak, the distance between the abscissa of two points on the curve whose ordinates are half of the maximum ordinate of the peak.

Note. – If the curve considered comprises several peaks, a full width at half maximum exists for each peak (based on IEV 391-15-08).

Full width at tenth maximum (FWTM)
Same as full width at half maximum except that measurement is made at one-tenth the maximum ordinate rather than at one-half (IEC Publication 340).

FWHM (see *full width at half maximum).*

FWTM (see *full width at tenth maximum).*

Geometry, detector
The physical configuration of a solid-state detector (IEC Publication 340).

Ion implanted contact
A detector contact consisting of a junction produced by the process of ion implantation.

Ion implantation
A process in which a beam of energetic ions incident upon a solid results in the implantation of those ions into the material.

Inactive region (of a semiconductor radiation detector)
A region of a detector in which charge created by ionizing radiation does not contribute significantly to the signal charge.

Integrated pulse
A pulse that is passed through a low-pass network, such as a single RC network or a cascaded RC network (IEC Publication 340).

Intrinsic semiconductor (I-type)
An effectively pure semiconductor in which, under conditions of thermal equilibrium, the charge carrier densities of each sign are nearly equal.

Note. – By extension, this term is incorrectly used to designate compensated semiconductors (IEV 391-05-02).

Junction
A transition layer between semiconductor regions of different electrical properties, or between a semiconductor and a superficial layer of different type. This layer is characterized by a potential barrier impeding the charge carriers to move from one region to the other (IEV 391-10-42).

Junction depth (of a p-n semiconductor radiation detector)
The distance below the crystal surface at which the conductivity type changes (IEC Publication 759).

Leakage current
The total detector current flowing at the operating bias in the absence of radiation (IEV 391-10-14).

Lithium-drifted semiconductor detector
A compensated semiconductor detector in which the compensated region is obtained by causing lithium ions to move through a P-type crystal under an applied electric field in such a way as to compensate the charge of the bound impurities (IEV 391-09-45).

Load impedance (of a semiconductor radiation detector)
The impedance shunting the detector, and across which the detector output voltage signal is developed.

Load resistance (of a semiconductor radiation detector)
The resistive component of the load impedance.

Noise linewidth
The contribution of noise to the FWHM of a spectral peak (IEC Publication 340).

Non-injecting contact (of a semiconductor radiation detector)
A contact at which the carrier density in the adjacent semiconductor material is not changed from its equilibrium value (IEC Publication 340).

Ohmic contact (of a semiconductor radiation detector)
A purely resistive contact, i.e., one that has a linear voltage-current characteristic throughout its entire operating range.

Peaking time (of an amplifier output pulse)
The time between the 1% and the 100% amplitude points on the leading edge of a pulse (provided that the pulse does not have a flat top). For flat topped pulses the peaking time is defined as the time between the 1% amplitude point and the mid-point of the flat top.

Per cent energy resolution (see *energy resolution (per cent)).*

p-i-n detector
A detector consisting of an intrinsic or nearly intrinsic region between a p and an n region.

Position-sensitive detector
A detector which measures the impact position, in one or more dimensions, of ionizing radiation upon the detector surface.

Pulse fall time (t_f)
The interval between the instants at which the instantaneous value last reaches specified upper and lower limits, namely, 90% and 10% of the peak pulse value unless otherwise stated.

Note. – In the case of a step function applied to an amplifier that has simple CR-RC shaping, the fall time is given by $t_f = 3.36$ CR).

Pulse rise time (t_r)
The interval between the instants at which the instantaneous value first reaches specified lower and upper limits, namely 10% and 90% of the peak pulse value, unless otherwise specified.

Note. – In the case of a step function applied to an RC low-pass filter, the rise time is given by $t_r = 2.2$ RC. In the case of a step function applied to an amplifier that has simple CR-RC shaping, i.e., one high-pass and one low-pass RC filter of equal time constants, the rise time is given by $t_r = 0.57$ RC) (IEC Publication 340).

Pulse duration (of an amplifier output pulse)
The time interval between the 50% of maximum amplitude points of a pulse.

Quasi-Gaussian shaping
Pulse shaping consisting of one differentiation followed by four or more integrations which results in a pulse shape that is approximated by a Gaussian curve. For n integrations, the shaping network is sometimes denoted as CR-$(RC)^n$.

Resolution, energy (per cent) (see *energy resolution (per cent))*.

Schottky barrier contact
A metal semiconductor contact structure whose rectification properties are heavily influenced by the difference in material work functions. These contacts frequently utilize an interfacial metal/semiconductor compound (e.g. a silicide).

Schottky barrier radiation detector
A semiconductor radiation detector whose blocking contact is a Schottky barrier contact.

Semiconductor, compensated
A semiconductor in which the effects of the impurities of a given type on the charge carrier density partially or completely cancel those of the other type. Such a semiconductor has properties which are similar to those of an intrinsic semiconductor (IEV 391-05-03).

Semiconductor detector
An ionization detector using a semiconductor medium in which an electric field is provided for the collection at the electrodes of the excess charge carriers produced by ionizing radiation (IEV 391-08-13).

Space-charge generation (in a semiconductor radiation detector)
The thermal generation of free charge carriers in the space-charge region (IEC Publication 340).

Space-charge region (of a semiconductor radiation detector)
A region in which the net charge density is significantly different from zero (see also depletion region).

Spectral line
A sharply peaked portion of the spectrum that represents a specific feature of the incident radiation, usually the full energy of a monoenergetic radiation.

Spectrum (of an ionizing radiation)
Distribution of the values of a specific radiation quantity, usually associated with energy, for example emission rate as a function of energy of emitted particles (IEV 391-15-07).

Straggling, energy
The random fluctuations in energy loss whereby those particles having the same initial energy lose different amounts of energy when traversing a given thickness of matter. (This process leads to the broadening of spectral lines.) (IEC Publication 340.)

Surface barrier contact
A rectifying contact that is characterized by a potential barrier associated with an inversion or accumulation layer; said inversion or accumulation layer being caused by surface charge resulting from the presence of surface states and/or work function differences (IEC Publication 759).

Surface barrier semiconductor detector
A semiconductor detector in which the potential barrier due to the junction results from a superficial inversion layer (IEV 391-09-42).

Sweep-out time, charge (of a semiconductor radiation detector) (see *charge collection time).*

Tailing time (of an amplifier output pulse)

The time between the 100% and 1% of maximum amplitude points on the trailing edge of a pulse (provided that the pulse does not have a flat top). For flat topped pulses, the tailing time is defined as the time between the midpoint of the flat top and the 1% of maximum amplitude point.

Totally depleted semiconductor detector

A semiconductor detector in which the thickness of the depletion layer is essentially equal to the thickness of the semiconductor material (IEV 391-09-49).

Total depletion voltage (of a semiconductor radiation detector)

The reverse voltage at which the depletion layer extends over essentially the whole thickness of the semiconductor (IEV 391-10-58).

Transmission detector

A totally depleted detector whose thickness, including its entrance and exit windows, is sufficiently small to permit radiation to pass completely through the detector.

Note. – This definition is for use with this standard.

Useful active dimension (of a position-sensitive detector)

A dimension (i.e. length, width) of that region of a position-sensitive detector over which the specifications of resolution and linearity are met.

Window (of a semiconductor radiation detector) (see *dead layer thickness).*

Window amplifier (see *biased linear amplifier).*

APPENDIX B

GENERAL INFORMATION CONCERNING SEMICONDUCTOR CHARGED-PARTICLE DETECTORS

B1. Interaction of charged particles with matter

Charged particles interact with matter by losing energy through:

1) inelastic collisions with atomic electrons;

2) inelastic collisions with atomic nuclei.

Other energy losses due to radiative processes and nuclear reactions are usually negligible.

For energetic charged particles ($\geqslant 1$ MeV/u), the energy loss is primarily due to collisions with electrons of the absorbing material. For each collision between a heavy charged particle and an electron, the amount of deflection and energy transfer are small. Many such interactions take place as the particle loses energy along a relatively straight trajectory. Under such conditions, the particles can be characterized by a definite range R and specific ionization loss (energy lost per unit path length) $\mathrm{d}E/\mathrm{d}x$, within the absorbing material.

For highly ionized particles, atomic displacements can become an important part of the energy loss process. This is the case for fission fragments, heavy ions, or lighter charged particles near the end of their range.

Energetic electrons also interact with matter through the Coulomb force. Because of the small mass of electrons, no significant energy is transferred to nuclei. However, at energies of more than a few megaelectronvolts (MeV), radiative processes (Bremsstrahlung) and pair production become significant in high Z material.

Because their mass to charge ratio is small, electrons are scattered along erratic tracks and the previous concept of range cannot be used. Instead, the concept of 10% transmission range may be applied. This range is that absorber thickness which results in 10% electron transmission at a given incident electron energy.

B2. Semiconductor charged-particle detector

B2.1 *The basic detector*

When charged particles interact with a semiconductor crystal, electrons are scattered in lattice bonds by the processes described in Clause B1, resulting in the creation of free electron-hole pairs. The average energy ε required to create a free electron-hole pair at a given temperature in a semiconductor is relatively insensitive to the type and energy of the ionizing radiation (for $E > \varepsilon$). Values of ε are 3.6 eV at room temperature in silicon, 3.8 eV at 80 K in silicon and 3.0 eV at 80 K in germanium. Therefore, for a given semiconductor at a given temperature, it is usual for the number of electron-hole pairs produced by the absorption of a charged particle to be directly proportional to that particle's energy.

Le détecteur est constitué d'un cristal semi-conducteur disposé entre deux contacts électriques. Le détecteur peut être une diode fonctionnant sous une tension de polarisation inverse. Cela est nécessaire pour atteindre une valeur suffisante du champ électrique entre les charge transport without excessive leakage current. If the resistivity of the semiconductor material is sufficiently high, rectifying contacts may not be necessary.

The application of bias voltage establishes a depletion region in which the concentration of charge carriers is greatly reduced and in which an electric field exists. Within this sensitive region, the free electron-hole pairs produced by a charged-particle interaction with the semiconductor material are swept to opposite contacts by the electric field. This process produces a current pulse at the input of a preamplifier. The integral of this pulse is a measure of the total signal charge and thus of the energy of the incident charged particle.

Due to a number of deleterious effects, the signal charge may be less than that expected. A significant part of this reduction may be due to energy lost in nuclear collisions within the detector. Such collisions may even give rise to reaction products which are detected separately. Another part of this signal loss may be attributed to poor charge collection from within the dense plasma created along the paths of some particles. The plasma shields electrons and holes from the electric field of the detector and favours electron-hole pair recombination. Another part of this signal loss may be attributed to charge trapping, low electric field and slow charge collection. Additionally, some of the incident particle's energy may be absorbed in a dead layer or window thereby contributing a reduced amount of charge to the detector output signal.

B2.2 *Geometry*

Charged-particle detectors are usually made in the planar configuration in which the two contacts are segments of parallel planes. The dimensions of the active region of the detector are usually determined by the dimensions of the contacts. Detectors may be partially depleted or totally depleted. In a partially depleted detector, the depletion region extends inward from the front contact but is separated from the back contact by undepleted material. In totally depleted detectors this depletion region extends from one contact to the other. Totally depleted detectors are used in (ΔE, E) telescopes and in timing measurements with heavy ions and fission fragments, as well as other applications requiring a very uniform sensitive depth.

Although planar detectors are usually made as disks, other shapes are sometimes used. Annular detectors may be employed to measure backscattering of a beam which passes through a hole in the detector. Detectors of the position-sensitive type are often made in a rectangular configuration. A coaxial cylinder geometry can be used to maximize detector active volume for a given depletion layer thickness. This is of primary importance for high energy gamma-ray detectors and for high range particles.

B2.3 *Material*

Charged-particle detectors are usually made of silicon, but germanium and other materials may also be used. The higher density of germanium results in a reduced range for energetic particles. Therefore, for a given detector thickness, particles of significantly higher energy shall preferably be studied with a germanium detector than may be studied with a silicon detector. However, silicon detectors are often more convenient to use because they may be operated at room temperature while germanium detectors must be operated at cryogenic temperatures. In addition, silicon detectors typically have thinner dead layers than germanium detectors.

The thickness of the depletion region which may be obtained with a given material is dependent on the purity of the material and the applied bias voltage. For silicon, the room temperature resistivity is often used as a measure of the purity of the material. As an example, a silicon detector with an electrically active impurity concentration of 1.1×10^{12} cm^{-3} (resistivity of 4 500 Ω · cm for N-type or 12 000 Ω · cm for P-type) requires a bias of 70 V to achieve a depletion region 300 μm thick.

Impurity concentrations in the 5×10^{11} cm^{-3} range (~10 000 Ω · cm to 20 000 Ω · cm, N-type) allow depletion layers of 1 mm to 1.5 mm to be obtained at several hundred volts bias. Silicon of sufficient purity (in the range of 1×10^{11} cm^{-3} or less) provides depletion layers of 3 mm to 5 mm with bias of 1 000 V or more. However, it is difficult to obtain silicon material of this purity.

The lithium compensation technique was developed to allow fabrication of Si(Li) detectors with depletion layers many millimetres thick starting with readily available material of relatively low resistivity. In this process lithium ions are drifted deep into the detector under the influence of an electric field in such a way that the lithium compensates the acceptor impurities in P-type silicon. This produces a region with material property nearly intrinsic. Such devices are sometimes referred to as PIN diodes.

Much work has been directed towards developing detectors for ionizing radiation from compound semiconductors such as mercuric iodide, cadmium telluride and gallium arsenide. Although the main advantages of such materials are probably in γ ray and X-ray applications, they may also prove useful for charged particles.

B2.4 *Fabrication*

After suitable semiconductor material is obtained, a detector shape is produced by slicing, dicing or other techniques. For thin ΔE detectors, special shaping techniques are required to assure that the detector thickness is sufficiently uniform. Treatments involving the bulk of the material, for example lithium compensation, may also be performed.

Non-injecting detector contacts must be fabricated. One of the contacts is usually a reverse-biased rectifying junction.

The rectifying contact can be a surface barrier, a Schottky barrier, a diffused, alloyed, or ion implantation junction.

Since one of the detector contacts serves as the entrance window, a dead layer associated with this contact directly affects the detector performance. One effect is a pulse height reduction due to the absorption of part of the energy of incident particles in the dead layer. Any variation in the angle of incidence of the particles or any non-uniformity in the dead layer thickness will cause variations in the amount of energy absorbed and result in spectral broadening. Even if the dead layer is uniform and the angle of incidence is constant, the energy loss in the dead layer undergoes fluctuations (which increase in magnitude with dead layer thickness) that contribute to spectral broadening. Depending on the nature of the dead layer and the ionizing radiation, some nonlinearity in energy response may also result.

Detector contacts have special significance for the position-sensitive detector which measures both the energy and the position of impact of a charged particle. One configuration of this detector utilizes a resistive contact which acts as a current divider. The output pulse height is representative of the impact position along the length of the detector. However, the resistive contact is a source of noise which reduces both the energy and spatial resolution of the device. In some applications this is overcome by the use of an array of separate detectors with individual outputs.

The fabrication of silicon or germanium detectors also requires the achievement of critical surface conditions through such techniques as etching and other chemical treatments. This is necessary to produce surfaces that can withstand high electric fields without producing excessive leakage current or electrical noise.

B3. Pulse shaping

In order to optimize the signal-to-noise ratio and count rate performance obtainable from any given semiconductor detector and amplifier combination it is necessary to use some form of electrical filtering procedure. This procedure is carried out by suitably designed electrical networks associated with the electronic amplifier system, and typically produces a pulse for each event registered by the detector. While the optimum pulse shape is known to be that of a symmetrical cusp, this is not generally employed for practical reasons. Instead it is more usual to use a "quasi-Gaussian" pulse shape produced by the action of one CR differentiator and four or more RC integrators having the general form shown in Figure B1, page 69. While the precise form of such a pulse is completely defined by specifying the nature of the pulse forming network and the time constant τ, it is useful to introduce some additional parameters as indicated in Figure B1. These are Δt, the FWHM of the pulse in time, together with the quantities t_p and t_t. The latter specify the "peaking time" t_p from 1% amplitude to the peak of the pulse on its leading edge, is designated as t_p and the corresponding pulse tailing time on the trailing edge as t_t. The quantity Δt dominates the S/N ratio of the filter, while t_p and t_t dominate its performance at high counting rates.

Although Δt is well defined and readily measurable for any pulse shape, t_p and t_t need redefining for pulses having flat tops such as those produced by delay-line shaping or trapezoidal filtering as indicated in Figure B2, page 69. Here the quantities are defined as in Figure B2. For amplifiers employing switchable time constants the relevant switch(es) should be specified in terms of Δt.

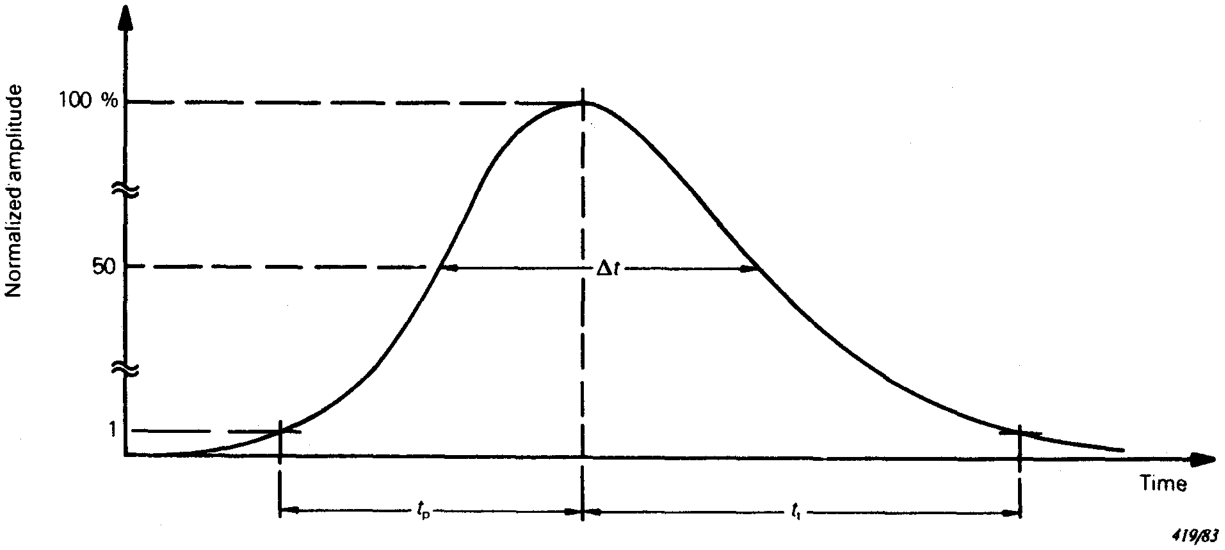

FIG. B1. - Quasi-Gaussian pulse shape.

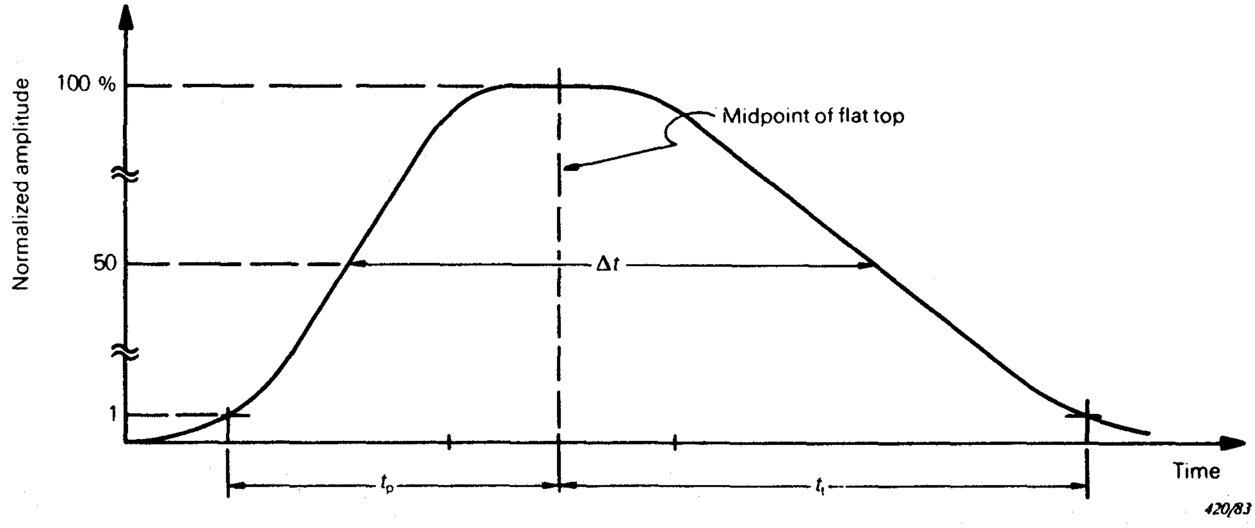

FIG. B2. - Trapezoidal pulse shape.